The Reproducibility and Validity of a Self-Administered Semiquantitative Food Frequency Questionnaire in Subjects from South Dakota and Wyoming

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Most validation studies of food frequency questionnaires have been done in populations capable of reporting their diet with unusual accuracy. In this study of ranchers and subjects selected at random, we compared nutrient intakes as assessed with multiple diet records with those assessed with a self-administered food frequency questionnaire (the Harvard-Willett instrument with 116 food items). One hundred thirty-eight subjects from South Dakota and Wyoming, 64 males and 74 females, completed at least one food frequency questionnaire and multiple 1-day diet records (mean = 5 days) during a 6-month to 1-year period. Of invited subjects, 88% participated; 59% of participants had a high school education or less. For 22 dietary nutrients (excluding supplements) and alcohol, the median crude correlation between intakes based on diet records and the food frequency questionnaire completed before the diet records was 0.42; after adjustment for energy, age, and sex, and after correction for attenuation in the correlation coefficients due to error from a limited number of diet records, the median correlation was 0.52. Correlations for men and women were similar. The validity of the food frequency questionnaire in this population was similar to that reported previously and supports the use of self-administered food frequency questionnaires in studies of general populations. (Epidemiology 1993;4:356–365)

Keywords: diet records, nutrition survey, nutrition assessment, questionnaires, reproducibility of results, data collection, validation study.

Self-administered food frequency questionnaires are a standard method for diet assessment in epidemiologic studies.[1] Such questionnaires are inexpensive to administer and process, and in studies of their validity, they have been found to be reasonably accurate.[2-4] Many validation studies of food frequency questionnaires, however, were conducted in populations that were likely to be capable of reporting their diet with unusual accuracy. For example, several previous validation studies have been conducted among participants in a 1-year observational dietary study,[5] among registered nurses,[4,6] or among health professionals.[7] In the present study, we examined the reproducibility and validity of a widely used dietary questionnaire[4] among men and women who were not selected on the basis of education or interest in diet.

Subjects and Methods

As part of a study of selenium intake in relation to health status, 138 subjects from western South Dakota and eastern Wyoming kept diet records and completed a food frequency questionnaire.[8] Demographic data for the participants are shown in Table 1. Thirty-four per cent of subjects were selected at random from telephone books. The rest of the subjects were selected because their ranches were located in areas with seleniferous soils. The subjects were paid to participate, and

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TABLE 1. Subject Characteristics

	Mean (SD) or Percentage (N = 138)
Age (years)	49 (14)*
Sex (% male)	46
Race (% white)	100
Education (% ≤ high school)	59†
Cigarette use (% current)	22
Body mass index (kg/m^2)	25.3 (4.5)

* Range = 22–82 years.
† Based on 132 subjects with known educational attainment.

88% of all potential subjects invited to participate did so. When one member of a given household was enrolled in the study, his or her spouse, if any, was also enrolled. Participants completed questionnaires regarding demographic characteristics, including level of education.

Participants were individually instructed at home in keeping diet records; training sessions lasted 20 minutes. In addition, written instructions for keeping records were left at each household. The subjects studied in 1985–1986 (approximately half of the participants) were assigned to keep diet records for 2 days during the summer, fall, and spring (6 days in total). For practical reasons, the rest of the subjects, studied in 1986–1987, were assigned to keep records for 2 days during the fall and spring (4 days in total). Most participants kept diet records for either 4 (38%) or 6 days (46%); the average number of records was 5 (range 2–8).

Nutrient intakes were calculated from diet records by CSG Holdings, Inc. (Rockville, MD), using their nutrient database, which is based on U.S. Department of Agriculture data,[9,10] supplemented with information from additional sources.[11–20] The diet record data were used to calculate mean daily intake of energy, 22 nutrients, and alcohol. Use of vitamin supplements was not uniformly noted on the diet records; use of supplements was therefore not considered in the calculations, nor in the calculations based on the food frequency questionnaires.

Subjects were asked to complete the self-administered food frequency questionnaire[4] twice: once before they had completed any diet records (first questionnaire), and again after they had finished keeping records (second questionnaire), 6–12 months later. The completed questionnaires were given a cursory check for completeness at the time they were collected. The questionnaire included 116 foods; participants were asked to report their frequency of use over the past year of a specific portion size of each food. For frequency of use, the nine response options ranged from never or almost never to six or more times per day. Nutrient intakes were calculated from the questionnaires using values from U.S. Department of Agriculture food composition tables,[9,10,21,22] additional publications,[12] and information from manufacturers. One participant indicated on her second questionnaire that she consumed meat as a main dish six or more times a day; the same frequency was noted for mixed dishes containing meat. Because these answers were implausible, the data from this person's second questionnaire were excluded.

Statistical Methods

We evaluated the reproducibility of the food frequency questionnaire by computing the Pearson correlation coefficient between intake of a nutrient calculated from the first and second food frequency questionnaires. We evaluated the validity of the food frequency questionnaire by examining the correlation between mean nutrient intake calculated from the diet records and intake calculated from either the first or second food frequency questionnaire. Before correlation coefficients were calculated, the nutrient intakes were transformed to normalize the distributions. In most instances, the transformation used was the natural log, and the resulting distribution did not depart materially from normality.[23] For 10 nutrients, we normalized the distribution by raising the value to a power; for another seven nutrients, there was no transformation that resulted in a normal distribution, and natural logarithms were used (these nutrients and the transformations used are listed in Appendix 1).

To examine the correlation between nutrient intakes after removing covariation due to total energy intake (and age and sex, where indicated), we used energy-adjusted nutrient intakes.[1] We calculated energy-adjusted nutrient intakes, which indicate the nutrient composition of the diet, by regressing nutrient intake on total energy intake (and age and sex, where indicated). We then calculated nutrient residuals (observed nutrient intake minus intake predicted on the basis of energy intake) for both the diet record and the food frequency questionnaire data; we examined the correlations between these adjusted values.

Observations for subjects from the same household were not independent. For the 63 spouse pairs, the median intraclass correlation coefficient for the energy-adjusted intake of 22 nutrients and alcohol was 0.42. Therefore, the size of our study was effectively less than the total number of subjects studied; the effective size for our correlations was somewhere between 75 (the number of households) and 130, the approximate number of subjects included in a given analysis.

We had on average only 5 days of diet records for each participant. Therefore, the correlations observed between long-term nutrient intake estimated by the diet records and that estimated from the questionnaire were attenuated owing to measurement error. To estimate the correlations that would have been observed had an infinite number of days of diet records been available for each subject, we calculated correlation coefficients corrected for measurement error using an approach like the method presently in wide use,[7] except that it accommodates a varying number of diet records per subject and is based on an unbalanced analysis of variance[24] (VF Flack, MP Longnecker, unpublished, 1992). Analyses were performed with the SAS statistical software package,[23] GAUSS,[25] and S-Plus.[26]

Results

One hundred twenty-eight subjects completed two food frequency questionnaires, and 138 subjects (64 males, 74 females) completed diet records and at least one food frequency questionnaire (Table 1).

Average Nutrient Intakes

The mean and standard deviation of energy intake calculated from the food frequency questionnaires was greater than that calculated from diet records (Table 2). Consequently, intake of most nutrients was somewhat greater when estimated by the questionnaire. Intake of vitamin A estimated by the questionnaire, however, was almost twice that estimated by the records. In contrast, the mean intake of magnesium estimated by the food frequency questionnaires was lower than in the diet records. When the analysis was restricted to those subjects who completed diet records and both of the food frequency questionnaires (N = 128), the findings were unchanged. The mean percentage energy from fat and other macronutrients was similar for diet records and the questionnaire.

Reproducibility

The median correlation between crude nutrient intakes (excluding energy intake) estimated from the two

TABLE 2. Mean Daily Intake of Energy, 22 Nutrients (Excluding Supplements), and Alcohol Measured by Diet Records and a Semiquantitative Food Questionnaire Completed on Two Separate Occasions (Standard Deviation in Parentheses)

	Diet Records (N = 138)	Food Frequency Questionnaire First (N = 134)	Food Frequency Questionnaire Second (N = 132)
Energy (MJ)	8.75 (2.84)	9.87 (3.69)	9.20 (2.95)
Carbohydrate (gm)	213 (73.1)	229 (88.0)	221 (84.2)
Fat (gm)	99.1 (37.6)	115 (52.8)	104 (38.9)
Protein (gm)	82.7 (29.0)	101 (39.7)	91.9 (31.7)
Vitamin A (IU)	6,680 (5,160)	11,600 (8,090)	10,600 (6,160)
Thiamin (mg)	1.38 (0.496)	1.42 (0.551)	1.39 (0.756)
Riboflavin (mg)	1.92 (0.776)	2.36 (1.10)	2.15 (0.995)
Niacin (mg)	25.4 (8.54)	38.5 (28.5)	37.9 (29.3)
Vitamin C (mg)	90.9 (49.8)	136 (70.4)	132 (82.5)
Calcium (mg)	817 (357)	834 (446)	784 (384)
Phosphorus (mg)	1,280 (452)	1,480 (571)	1,380 (487)
Iron (mg)	13.9 (4.65)	15.7 (5.96)	14.7 (5.20)
Magnesium (mg)	298 (97.8)	207 (85.8)	203 (81.1)
Vitamin B_6 (mg)	1.67 (0.627)	2.00 (0.747)	1.86 (0.643)
Vitamin B_{12} (μg)	6.42 (6.34)	9.17 (4.46)	8.62 (4.73)
Vitamin D (IU)	163 (171)	229 (152)	227 (145)
Folate (μg)	191 (198)	282 (126)	257 (104)
Potassium (mg)	2,710 (902)	3,300 (1,110)	3,100 (1,000)
Cholesterol (mg)	355 (183)	481 (282)	423 (204)
Saturated fatty acids (gm)	28.9 (13.7)	42.9 (20.5)	38.6 (15.2)
Monounsaturated fatty acids (gm)	31.1 (14.1)	47.0 (23.4)	42.3 (16.8)
Polyunsaturated fatty acids (gm)	13.2 (6.04)	18.4 (8.58)	17.1 (7.16)
Crude fiber (gm)	3.48 (1.52)	4.81 (1.98)	4.51 (1.82)
Alcohol (gm)	2.33 (5.59)	4.1 (6.7)	3.8 (8.2)
Percent calories from:			
Carbohydrate	41.2 (7.28)	39.4 (8.55)	40.4 (8.78)
Fat	42.4 (6.00)	43.2 (7.15)	42.6 (6.92)
Protein	16.0 (2.68)	17.1 (2.33)	16.8 (2.63)

food frequency questionnaires was 0.54 (range = 0.40–0.81) (Table 3). Adjustment of nutrient intakes for energy intake (or energy intake, age, and sex) slightly increased the median correlations. The reproducibility of alcohol consumption was greater than for nutrients (crude r = 0.81). The reproducibility of percentage energy from macronutrients was slightly less than that for most nutrients. Among males, the median correlation for the energy-adjusted intakes (of 22 nutrients and alcohol) was 0.64, and among females the median was 0.57. Among subjects with a high school education or less, the median correlation was 0.52, and among more educated subjects, the median correlation was 0.61.

The interval between the first and second administration of the food frequency questionnaire was about 1 year for 71 subjects and approximately 6 months for 57 subjects. To determine whether the reproducibility of dietary data differed between these two groups, we examined correlations by interval. The Pearson correlation coefficient for energy intake for the 1-year interval group was 0.30, and for the 6-month interval group was 0.40. The median correlation between energy-adjusted nutrient intakes for the 22 nutrients and alcohol, however, was 0.60 for the 1-year group and 0.60 for the 6-month group. Thus, it appeared that energy-adjusted nutrient intake was affected less by the interval between administrations than was energy intake. Differences between the subjects in each interval group also may have accounted for part of the small disparity in reproducibility of energy intake.

VALIDITY

The correlation between energy intake calculated from diet records and from the food frequency questionnaire was greater for the first questionnaire than for

TABLE 3. Pearson Correlation Coefficients between Intake of Energy, 22 Nutrients, and Alcohol Measured by a Food Frequency Questionnaire on Two Occasions, According to Type of Adjustment*

	Crude (N = 128)	Energy-Adjusted (N = 128)	Energy-, Age-, and Sex-Adjusted (N = 128)
Energy	0.39		
Carbohydrate	0.53	0.49	0.47
Fat	0.42	0.65	0.65
Protein	0.40	0.57	0.54
Vitamin A	0.60	0.61	0.58
Thiamin	0.54	0.50	0.49
Riboflavin	0.59	0.62	0.62
Niacin	0.61	0.62	0.62
Vitamin C	0.55	0.57	0.53
Calcium	0.64	0.58	0.57
Phosphorus	0.55	0.64	0.64
Iron	0.42	0.56	0.56
Magnesium	0.67	0.68	0.67
Vitamin B_6	0.40	0.65	0.65
Vitamin B_{12}	0.62	0.62	0.61
Vitamin D	0.70	0.57	0.55
Folate	0.55	0.58	0.57
Potassium	0.49	0.61	0.60
Cholesterol	0.49	0.48	0.48
Saturated fatty acids	0.42	0.58	0.57
Monounsaturated fatty acids	0.44	0.69	0.68
Polyunsaturated fatty acids	0.43	0.43	0.43
Crude fiber	0.52	0.53	0.45
Alcohol	0.81	0.80	0.76
Median of above†	0.54	0.58	0.57
Percent energy from:			
Carbohydrate	0.51		0.49‡
Fat	0.50		0.47
Protein	0.44		0.43

* Transformed by $\log_e$ or a power to improve normality (see Appendix 1). Nutrient intakes from supplements not included.
† Energy intake is not included in calculation of median.
‡ Adjusted figures for energy density are not energy-adjusted.

the second (Table 4). The median correlation between crude intake of 22 nutrients and alcohol, however, did not differ substantially between questionnaires. The crude correlation coefficients for individual nutrients ranged from 0.21 (niacin) to 0.60 (calcium).

Adjustment of nutrient intakes for energy, or energy, age, and sex had on average little effect on the correlations. When the analysis was restricted to those subjects who completed both food frequency questionnaires, the results were essentially the same. The validity of macronutrient intakes were about the same when expressed as nutrient densities. Median energy-adjusted correlation coefficients for males and females were approximately the same (male $r = 0.42$, female $r = 0.39$). Because, in some households, wives may have completed food frequency questionnaires or kept diet records for their husbands, our ability to detect sex differences in validity may have been compromised. Correlation coefficients in subjects with a high school education or less (median $r = 0.45$) were about the same as in subjects with more than a high school education (median $r = 0.39$).

The correlation coefficients corrected for day-to-day variation in diet record intakes had a median value that

TABLE 4. Pearson Correlation Coefficients between Intake of Energy, 22 Nutrients, and Alcohol Estimated by Diet Records and the First and Second Food Frequency Questionnaires (FFQ)*

	Crude (Uncorrected†) FFQ		Energy-Adjusted (Uncorrected) FFQ		Energy-Age-Sex-Adjusted (Uncorrected) FFQ		Energy-Age-Sex-Adjusted (Corrected†) FFQ	
	1st (N = 134)	2nd (N = 132)	1st (N = 134)	2nd (N = 132)	1st (N = 134)	2nd (N = 132)	1st (N = 134)	2nd (N = 132)
Energy	0.51	0.38						
Carbohydrate	0.47	0.50	0.44	0.53	0.43	0.51	0.54	0.62
Fat	0.51	0.34	0.45	0.44	0.44	0.43	0.59	0.58
Protein	0.45	0.34	0.33	0.29	0.37	0.33	0.52	0.45
Vitamin A	0.35	0.47	0.40	0.48	0.38	0.43	0.60	0.69
Thiamin	0.46	0.36	0.34	0.40	0.33	0.38	0.50	0.52
Riboflavin	0.46	0.47	0.48	0.44	0.47	0.44	0.63	0.57
Niacin	0.24	0.21	0.24	0.23	0.25	0.24	0.29	0.28
Vitamin C	0.38	0.50	0.47	0.50	0.46	0.43	0.51	0.46
Calcium	0.57	0.60	0.60	0.57	0.60	0.57	0.74	0.69
Phosphorus	0.53	0.48	0.53	0.55	0.55	0.56	0.66	0.67
Iron	0.46	0.35	0.35	0.42	0.35	0.43	0.43	0.52
Magnesium	0.42	0.47	0.57	0.49	0.60	0.50	0.70	0.60
Vitamin B_6	0.37	0.35	0.35	0.40	0.34	0.40	0.43	0.49
Vitamin B_{12}	0.36	0.41	0.35	0.40	0.37	0.41	0.72	0.78
Vitamin D	0.38	0.55	0.30	0.45	0.28	0.43	0.31	0.44
Folate	0.35	0.35	0.33	0.39	0.31	0.37	0.42	0.45
Potassium	0.45	0.41	0.51	0.28	0.52	0.25	0.63	0.34
Cholesterol	0.39	0.37	0.31	0.42	0.30	0.41	0.46	0.63
Saturated fatty acids	0.52	0.36	0.38	0.38	0.41	0.40	0.55	0.56
Monounsaturated fatty acids	0.50	0.37	0.36	0.35	0.39	0.38	0.50	0.51
Polyunsaturated fatty acids	0.34	0.37	0.26	0.28	0.26	0.29	0.42	0.43
Crude fiber	0.38	0.44	0.44	0.44	0.40	0.37	0.52	0.49
Alcohol	0.39	0.42	0.35	0.40	0.31	0.37	0.46‡	0.45‡
Median of above§	0.42	0.41	0.36	0.42	0.38	0.41	0.52	0.52
Percent calories from:								
Carbohydrate	0.44	0.55			0.41¶	0.53	0.53¶	0.59
Fat	0.51	0.33			0.45	0.30	0.58	0.48
Protein	0.37	0.30			0.34	0.32	0.48	0.45

* Variable transformations other than natural logarithms are described in Appendix 1. Nutrient intakes from supplements are not included.

† Uncorrected and corrected refer to adjustment for measurement error due to the limited number of diet records per subject.

‡ Calculated using the inverse variance weighted average method. The rest were calculated using the unbalanced analysis of variance method. See text.

§ Medians exclude energy intake.

¶ Adjusted figures for energy density are not energy-adjusted.

was about 0.1 higher than for the uncorrected coefficients. Of the various sets of correlations shown, the correlations corrected for measurement error best represent the ability of the food frequency questionnaire to assess long-term diet.

We calculated the mean intake of selected nutrients from diet records for groups of subjects who were defined by quartile of intake of the same nutrient on the food frequency questionnaire (Table 5). Except for vitamin A and percentage of calories from fat, mean intakes increased monotonically across quartiles. Use of these data is illustrated as follows: with questionnaire data, one might erroneously believe that the average contrast in percentage of calories from fat between the highest and lowest quartiles was 18% (data not shown), whereas from Table 5, it is evident that the actual difference is 6.4% (45.6%-39.2%).

Validation data such as these can be used to fit models of true nutrient intake (from diet records) as a function of measured intake (from a food frequency questionnaire).[1] The nutrient coefficients from regression models (Table 6) can be used to assess the effect of measurement error (due to use of a food frequency questionnaire) on the nutrient effect estimates in epidemiologic studies. We illustrate how these coefficients may be used in the Discussion.

Discussion

The validity of diet assessment by food frequency questionnaire in this study of a Midwestern population was similar to what others have found (Table 7). The number of days of diet records varied across studies, complicating comparison of results. This comparability problem, however, can be reduced by comparing correlations adjusted for within-person variation. Two authors[7,27] presented such coefficients, and their median (0.63, see Table 7) was only slightly larger than

TABLE 5. Mean Intake of Selected Nutrients from Diet Records within Quartiles of Intake Determined by the First Food Frequency Questionnaire (FFQ) (N = 134)

	Quartile of Nutrient Intake According to FFQ			
Nutrient	Q_1	Q_2	Q_3	Q_4
Energy (MJ)	7.10	8.15	9.55	10.30
Fat (gm)	78.4	86.5	109	125
Percent calories from fat	39.2	42.9	42.1	45.6
Vitamin A (IU)	4,420	6,920	6,510	9,050
Calcium (mg)	617	751	805	1,110
Cholesterol (mg)	295	316	361	455

TABLE 6. Least Squares Regression Coefficients That Can Be Used to Adjust Epidemiologic Regression Coefficients for Attenuation Owing to Error in Measurement from Use of a Food Frequency Questionnaire*

	Present Study	Rimm *et al*[7]
Energy	0.31	0.28
Carbohydrate	0.34	0.63
Fat	0.39	0.60
Protein	0.45	0.21
Vitamin A	0.39	0.46
Thiamin	0.32	0.68
Riboflavin	0.48	0.46
Vitamin C	0.51	0.66
Calcium	0.46	0.46
Phosphorus	0.53	0.55
Iron	0.38	0.30
Magnesium	0.34	0.73
Vitamin B_6	0.43	0.85
Vitamin B_{12}	0.44	0.32
Folate	0.48	0.84
Potassium	0.56	0.62
Cholesterol	0.40	0.63
Saturated fatty acids	0.57	0.77
Monounsaturated fatty acids	0.53	0.61
Polyunsaturated fatty acids	0.32	0.27
Crude fiber	0.45	0.86
Median†	0.44	0.61

* Coefficients for the present study are adjusted for energy, age, and sex. The coefficients from the study of men by Rimm *et al*[7] are energy-adjusted. Rimm *et al* studied dietary fiber; in the present study, crude fiber was examined. Data apply to use of the Harvard-Willett food frequency questionnaire. For both studies, the results shown are for calculations with nutrient intakes from supplements excluded. Data from the present study are based on the results from the first questionnaire.

† Medians exclude energy intake.

our value (0.55). The volunteers in the 1987 study by Willett *et al*[5] kept diet records for 1 year; the large number of diet records suggests that the coefficients (median = 0.53) were unlikely to be attenuated due to error from within-person variation. The results of the other studies, if deattenuated for day-to-day variation in diet record intake, would likely be in the same range as those for the present study and those of Rimm *et al*[7] and Block *et al*.[27]

The populations or design of the other studies might have enhanced the validity found for the questionnaires. For example, health professionals might be more diet conscious than average and might be especially good at keeping accurate records. The subjects in the 1990 study by Block *et al*[2] were volunteers for a dietary intervention study and thus likely to have been unusually aware of their diets. In the 1992 study by Block *et al*,[27] less than 40% of the target population completed the questionnaires, leaving open the possi-

TABLE 7. Summary of Seven Studies of the Validity of Food Frequency Questionnaires (FFQs) for Assessment of Recent Diet: Study Characteristics and Pearson Correlation Coefficients between Intake of Energy and of Nine Nutrients Measured by FFQs and Diet Records*

	Questionnaire						
	Willett (Present Study)	Willett[7] (1992)	Willett[4] (1988)	Willett[5] (1987)	Block[27] (1992)	Block[2] (1990)	Pietinen[3] (1988)
No. of days of diet records	5	14	28	365	16	12	24
No. of foods on FFQ	116	131	116	116	98	94	276
Population	Cross-section	Health professionals	Nurses	Volunteers	Cross-section	Volunteers	Cross-section
Sex	Both	Males	Females	Both	Both	Females	Males
Number	132	127	150	27	76	102	141
Energy	0.51	0.27	0.37	0.67	0.62	0.51	0.57
Carbohydrate	0.47	0.40	0.47	0.60	0.68	0.51	0.60
	0.44†	0.62	0.61	0.51		‡	0.55
	0.54§	0.65			0.72		
Fat	0.51	0.42	0.37	0.76	0.58	0.60	0.51
	0.45	0.48	0.54	0.51			0.39
	0.59	0.53			0.63		
Protein	0.45	0.22	0.29	0.66	0.56	0.48	0.53
	0.33	0.28	0.54	0.43			0.63
	0.52	0.32			0.61		
Vitamin A	0.35	0.49	0.26	0.63		0.47	0.41
	0.40	0.56	0.37	0.68			0.31
	0.60	0.71					
Vitamin C	0.38	0.50	0.50	0.38	0.54	0.56	0.58
	0.47	0.57	0.54	0.46			0.58
	0.51	0.65			0.63		
Calcium	0.57	0.44	0.46	0.63	0.56	0.56	0.61
	0.60	0.45	0.51	0.55			0.68
	0.74	0.51			0.59		
Potassium	0.45	0.41	0.41	0.44	0.60	0.55	0.53
	0.51	0.56	0.53	0.59			0.57
	0.56	0.63			0.63		
Cholesterol	0.39	0.57	0.50	0.67	0.59	0.55	0.54
	0.31	0.59	0.57	0.38			0.57
	0.46	0.67			0.66		
Saturated fatty acids	0.52	0.52	0.38	0.74	0.58	0.63	0.56
	0.38	0.59	0.54	0.60			0.62
	0.55	0.63			0.64		
Median¶	0.45	0.44	0.41	0.66	0.58	0.55	0.54
	0.44	0.56	0.53	0.51			0.57
	0.55	0.63			0.63		

* Correlations are between nutrient intakes exclusive of vitamin supplements. Values from present study are from the first food frequency questionnaire. The 1992 Block study used both diet records and 24-hour recalls as the standard.

† Second row of correlations are energy-adjusted.

‡ Block *et al* found that the correlations between energy-adjusted intakes were not materially different from those for the unadjusted values.

§ Third row of correlations are adjusted for measurement error. The values for the present study and Willett's 1992 study are also adjusted for energy. In addition, values for the present study are adjusted for age and sex.

¶ Medians are of the nine nutrients (energy intake not included). No vitamin A data were available for the 1992 Block study.

bility that the participants were atypical or especially interested in diet. Pietinen *et al*[3] might have found higher validity because they used an extremely detailed (276-item) questionnaire that required over 2 hours to complete, and furthermore, the questionnaire was reviewed in person with a dietitian.

Although not all subjects were chosen at random, we believe that our target population was representative of those residing in western South Dakota and eastern Wyoming. Of those asked to participate, 88% did so, demonstrating that this was not a select population. Because of possible regional differences in populations that might affect the validity of the food frequency questionnaire, however, or because by paying subjects our results were unusually good, our findings provide only indirect evidence that this questionnaire is reasonably valid in the general U.S. population.

Two features of our study may have decreased the correlation coefficients. In validation studies in which the food frequency questionnaire is administered twice, the correlations of nutrient intake with those from diet records is usually higher for the second questionnaire.[3,6] Presumably, this finding results from an increased dietary awareness due to the keeping of records, and because the period inquired about brackets when the records were kept. In the present study, contrary to expectation, the correlation for energy intake was lower with the second questionnaire. These correlations might have been lower because concurrently with the diet records one subject in each household saved duplicate plate food specimens, and this process is known to affect short-term diet.[28] Second, in the present study, in a given season 88% of records were kept on consecutive days. Because diets on consecutive days tend to be correlated,[29] it is likely that we underestimated the within-person variation. Thus, the error-adjusted coefficients may be artificially low. In addition, the effect of dietary supplements on the validity of diet assessment was not considered in the present study; in general, validation coefficients are greater when supplement use is included in calculations of nutrient intake.

Self-administered food frequency questionnaires have been criticized because, in one study,[30] the validation coefficients based on the self-completed Block instrument were lower than those based on an identical interviewer-administered instrument. In that study, many of the respondents skipped food items on the self-administered questionnaire (21% skipped 16 or more food items). In a subsequent study using the same self-administered questionnaire, however, there were many fewer skipped foods.[31] Skipped foods may be even less common with the Harvard-Willett questionnaire.[31] The present findings indicate that self-administered food frequency questionnaires can provide a reasonably valid method of diet assessment.

The attenuation in nutrient effect estimates due to measurement error incurred by use of this food frequency questionnaire is illustrated by the following calculations, based on the validation coefficients in Table 6. If, for example, the observed relative risk of a disease associated with a decrease in intake of 400 mg calcium per day were 2, using the beta coefficient for calcium in the present study (0.46), the actual relative risk (RR) would be 4.5 (the natural log of 2 is 0.693, $4.5 = e^{0.693/0.46}$),[1] meaning the effect size (RR − 1) observed was about 25% of true. The median beta coefficient in Table 6 for the present study was 0.44, suggesting that effect estimates will be roughly 25% of true. Similar calculations using the median beta from Rimm *et al*[7] show that the true effect size is underestimated by about 50%. The present study and that of Rimm *et al*[7] may well characterize the range of validity found in the studies summarized in Table 7. These results suggest that in epidemiologic studies of nutrient effect, with intake modeled as a continuous variable,[32] estimates of effect size are in general one-quarter to one-half of their true size.

Although greater validity is desirable, the consistency of results across validation studies indicates that the correlations are limited by error in diet records and in the food frequency questionnaires. For example, if, in keeping diet records, the portion size of some foods is estimated from dimensions or household measures instead of weight, the nutrient content may, on average, be off by 20%.[33] In addition, several studies have demonstrated that subjects tend to underreport food intake on diet records.[33-35] Hunter *et al*[36] recently found that polyunsaturated fat content in fat biopsies was correlated with diet record-based intake estimates ($r = 0.49$) to the same extent as those based on food frequency questionnaires ($r = 0.50$). Their results provide further evidence that diet records, the gold standard measure of diet intake, may have a degree of error similar to food frequency questionnaires.

In other studies of the reproducibility of food frequency questionnaires, correlations have been slightly higher than in this study, in which the range of correlations was 0.39–0.81. Pietinen *et al*[3] found that the range of intraclass correlations for repeated administrations was 0.56–0.88. Willett *et al*,[5] in a study of the reproducibility of an earlier version of his questionnaire, found that the range of correlations was

0.54–0.71. Reported intake of alcohol appears to be particularly reproducible with food frequency questionnaires.[3,37]

The coefficient for the validity of alcohol in this study is not as high as in other studies.[3,37] This discrepancy may exist because just 19% of the diet records were kept on Friday or Saturday, as compared with 28% if all days of the week had been equally represented.

Because the subjects in the present study were not selected to have high education or special interest in diet, and because their participation rate was high (88%), the findings on questionnaire validity from this study are likely to be more representative of its performance in a general population than in most previous validation studies. Our findings that the degree of validity in this population was similar to that reported previously supports the use of self-administered food frequency questionnaires for studies in general populations.

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Appendix 1

TABLE A1. Variable Transformations Other Than Natural Logarithms Used to Normalize Distribution of Nutrients*

Nutrient	Source of Data†	Transform
Folate	Second FFQ	$x^{0.5}$
Vitamin D	Second FFQ	$x^{0.5}$
Vitamin B_{12}	Second FFQ	$x^{0.4}$
Carbohydrate	Second FFQ	$x^{0.3}$
Fiber	Second FFQ	$x^{0.5}$
Vitamin A	Second FFQ	$x^{0.3}$
Vitamin B_6	Diet records	$x^{0.1}$
Cholesterol	Diet records	$x^{0.5}$
Polyunsaturated fatty acids	Diet records	$x^{0.5}$

* Normality of distribution was determined using the Kolomogorov *D* statistic (normal if $P > 0.05$).
† FFQ = food frequency questionnaire.

TABLE A2. Variables for Which No Normalizing Transformation Was Used*

Nutrient	Source of Data†
Thiamin	Second FFQ
Niacin	First FFQ
Niacin	Second FFQ
Vitamin B_{12}	Diet records
Vitamin B_{12}	First FFQ
Vitamin D	Diet records
Folate	Diet records
Alcohol	Diet records
Alcohol	First FFQ
Alcohol	Second FFQ

* When no normalizing transformation was identified, the natural logarithm of the value was used in the analyses.
† FFQ = food frequency questionnaire.